

Preliminary Analysis of Target Shock Response to Beam Deposition

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Sudden proton beam deposition in the graphite target will result in an instant rising of temperature inside the target. This, in turn, results in the corresponding rising of the thermal pressure which causes the excitation of sound waves, i.e., formation of shock and rarefaction waves. During these excitations, the pressure oscillates with magnitude $\pm \Delta P$ of few tens katm above the corresponding initial thermal pressure.

Initially, the proton beam deposits part of its energy in the solid graphite target heating it to higher temperatures as it passes through the target media. The deposition time, τ_b , of few nanoseconds is usually much less than the sound travel time, τ_s , of tens or hundred microseconds: $\tau_s \approx L/C_s$, with L being the characteristic size, $L \approx 1-30$ cm, and C_s is the sound speed of about few km/s. Therefore for shorter deposition time, the deposited energy can not be spread over the medium beyond the deposition area. The energy deposition, therefore, can be regarded as instant from hydrodynamic point of view. In addition, since thermal conduction requires more time for energy redistribution, only hydrodynamic phenomena should be taken into account in the case of very short deposition time. For longer beam deposition time, that is in the order or longer than the sound wave propagation time in the target media, the resulting pressure is significantly reduced.

For cylindrical targets the instant rising of the pressure results in the excitation of sound waves in both the radial direction, r , and the longitudinal direction, z , with corresponding

characteristic times $\tau_R = R/C_s$ and $\tau_L = L/C_s$ where R and L are target sizes in r and z directions. During such excitations the pressure oscillates in each direction with magnitude $\Delta P(r,z)$, in which $P_{\max}(r,z) = +\Delta P$, $P_{\min}(r,z) = -\Delta P$. The magnitude of these pressure (stresses) oscillations along with other factors will determine the ultimate lifetime of the target. Although solid targets such as graphite can withstand positive pressure of several kbar but it may be less resistant against negative pressures. Also for many cycles fatigue can take place and further reduce target strength. In addition, target strength can be significantly reduced with increasing radiation damage dose, i.e., the dpa rate.

The HEIGHTS package developed at Argonne National Laboratory is used to predict target behavior and dynamics as a result of sudden energy deposition [1-3]. The HEIGHTS package solves the hydrodynamic equations of mass, momentum, and energy for solid or liquid targets in different geometry and in strong magnetic field environment.

Figure 1 shows a preliminary calculation of the dependence of the total resulting pressure on the energy deposition time. The calculation is made for a cylindrical graphite target of 7 mm radius (current Neutrino target design) and an average energy deposition of 20 J/g (corresponding to 16 GeV proton beam of 4 MW power incident on graphite target with 15 Hz). At very short deposition time the resulting pressure in the graphite target is significantly high and it decreases substantially as the deposition time increases to the order of the sound propagation time in the target. The magnitude of the resulting pressure (stress) also decreases with lower beam power.

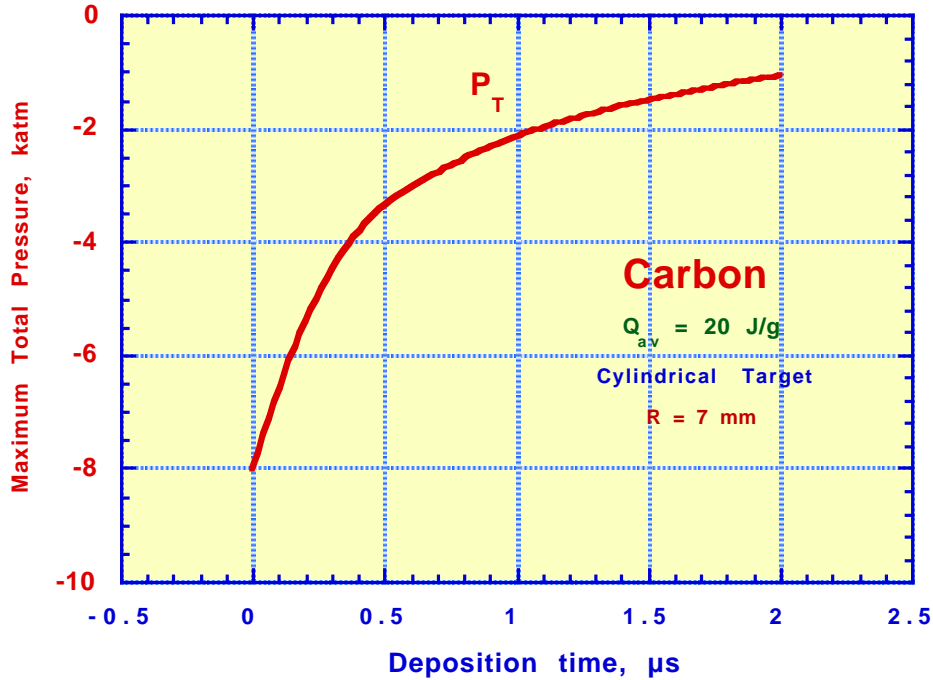


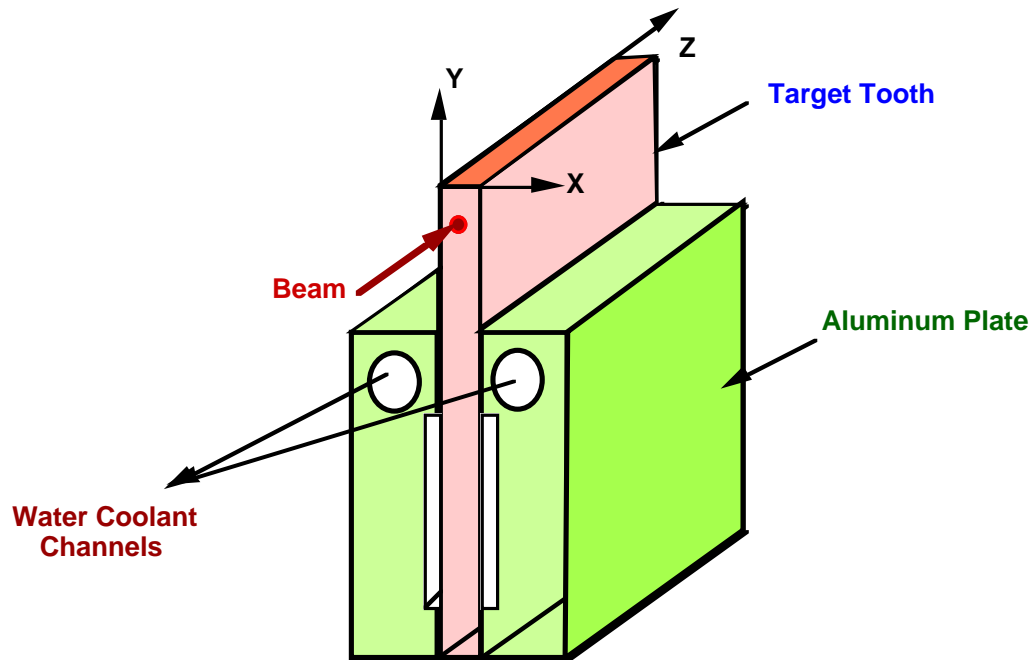
Fig. 1 HEIGHTS Calculations of Dependence of Total Pressure on Energy Deposition Time

The magnitude of the resulting pressure waves and stresses also depends on target design and configurations. Figure 2 shows two different designs, i.e., the NUMI and Neutrino target systems. The NUMI target consists of graphite plate attached to aluminum plates cooled with water. The Neutrino target consists of a bare cylindrical graphite rod of 7 mm radius and 80 cm long. The long fin structure of the NUMI target tooth as well as the longer deposition time will help in dissipating the sound pressure waves resulting from beam deposition. This is shown in Fig. 3 comparing a preliminary calculation of the total resulting pressure in both target systems for beam power of about 1 MW. A simple grid is used to simulate the target along with a simple equation-of-state is used for graphite for faster computer simulation. The beam profile is assumed Gaussian in the

radial direction for the cylindrical target and Gaussian in x- and y-directions for the NUMI target with different σ . For the cylindrical target geometry accumulation of rarefaction waves may take place on the target axis. Target cooling and structure systems, which may be required however, can increase pion absorption and reduce the final muon production.

More detailed analysis is needed to evaluate the overall response of solid targets to pulsed and high power beam deposition. The effect of the oscillating and the resulting negative pressure on the strength and fatigue lifetime of solid targets needs further study. The effect of beam and particle radiation damage on the solid target properties and lifetime is another important factor that requires detail analysis and simulation. Various options of cooling the target need to be investigated in detail coupled with the overall target design.

NUMI TARGET DESIGN



NEUTRINO-FACTORY TARGET DESIGN

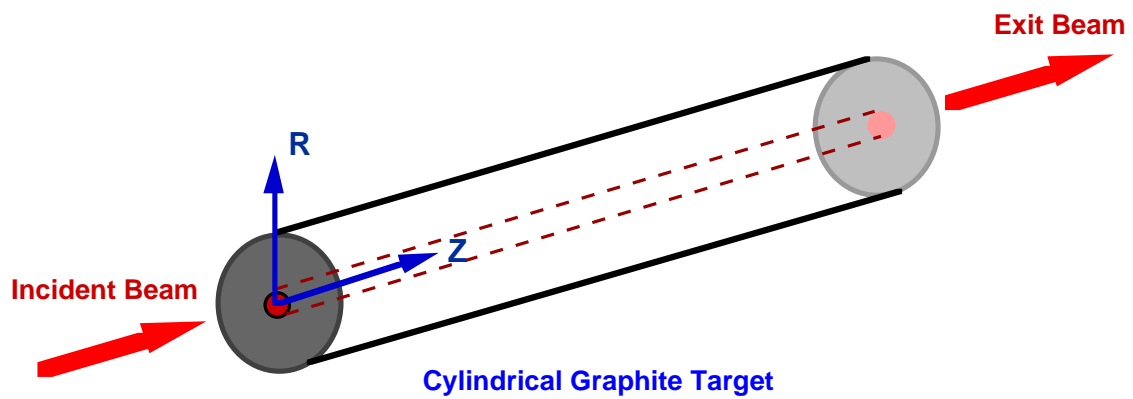


Fig. 2 NUMI and Neutrino-Factory Target Design System

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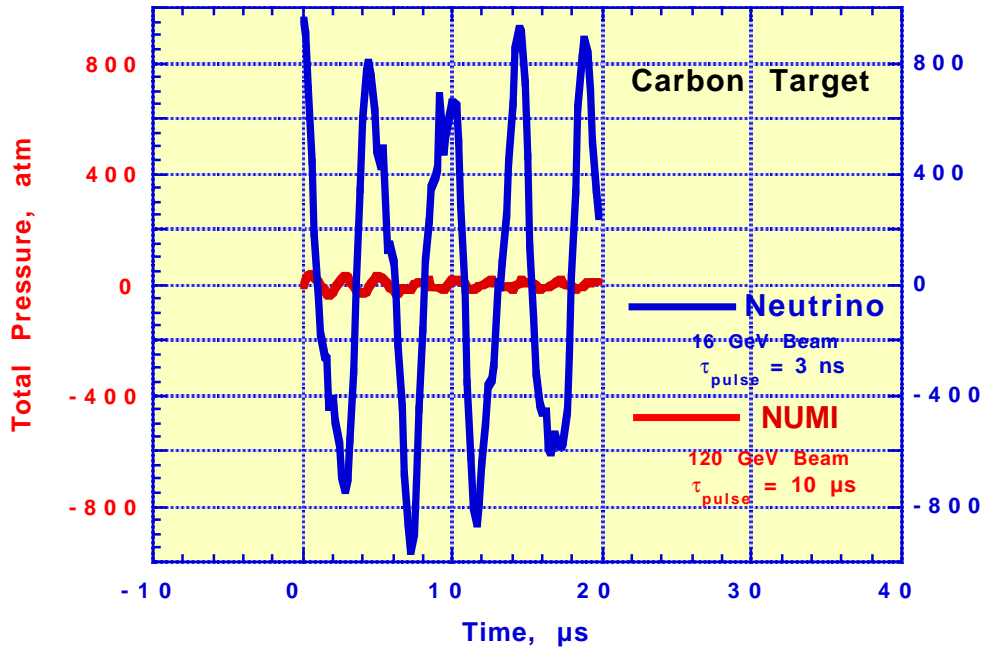


Fig. 3 HEIGHTS Calculations of NUMI and Neutrino Target Total Pressure Oscillations Following Beam Deposition

References

- [1] A. Hassanein, et al, "The Design of a Liquid Lithium Lens for a Muon Collider," Proc. Int. Conf. Accelerators, N.Y. (1998).
- [2] A. Hassanein, "Simulation of Intense Heating and Shock Hydrodynamics in Free-Moving Liquid Targets," Proc. Nuclear Applications of Accelerator Technology, **ACCApp'99**, ANS meeting, Long Beach, Ca (1999) 276-286.
- [3] A. Hassanein, "Liquid Metal Targets for High-Power Applications: Pulsed Heating and Shock Hydrodynamics," **J. Laser and Particle Beams**, **18** (2000) 611.